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(71) Applicant: SIGNAFY, INC. [US/US]; 4 Independence Way, Princeton, NJ 08540 (US).

(72) Inventors: MILLER, Matthew, L.; 44 Tee-Ar Place, Princeton, NJ 08540 (US). WU, Min; 228A Harrison Lane, Princeton, NJ 08540 (US).

(74) Agents: GROLZ, Edward, W. et al.; Scully, Scott, Murphy & Presser, 400 Garden City Plaza, Garden City, NY 11530 (US).

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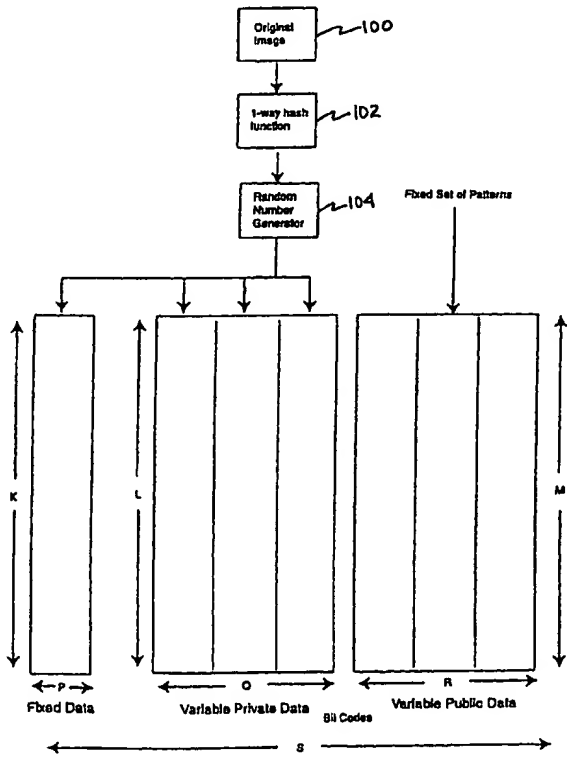
(54) Title: COMBINING MULTIPLE MESSAGES WITH DIFFERENT CHARACTERISTICS FOR WATERMARKING

(57) Abstract

A method for inserting at least two messages into digital data (100) having the steps of: deriving the messages using a hash of the data (102) as a seed to a random number generator (104); representing each of the messages with an individual signal such that all of the individual signals, when combined, do not interfere with one another and each individual signal has its own robustness characteristics; combining the individual signals to create a watermark signal; and inserting the watermark signal into the digital data to be watermarked. Also provided is a method for detecting a target message from digital data containing at least two watermark messages.



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COMBINING MULTIPLE MESSAGES WITH DIFFERENT CHARACTERISTICS FOR WATERMARKING

The present invention relates generally to inserting a watermark into digitized data. Specifically, this invention relates to inserting a combined watermark into digital data, the combined watermark containing at least two messages, each message having different characteristics such as robustness.

There are many proposals for watermarking media content, [see *A review of watermarking and the importance of perceptual modeling*, I.J., Cox, Matt Miller, Proceedings of SPIE, Human Vision and Electronic Imaging II, Vol.3016, pp 92-99, February 1997]. Generally, watermarking is a process whereby a message is inserted into multimedia content by modifying the media data itself, i.e., in the case of imagery, the pixel intensities may be altered in an imperceptible way, but in a manner that is detectable by a computer or other device. We define the difference between the original and watermarked data immediately after watermark insertion as the watermark signal. This signal can be constructed in many different ways. For example, a unique pseudo-random noise (PN) sequence can be used to represent an arbitrarily long message that is determined by using the PN sequence as an index into a database. Alternatively, a n-bit sequence may be directly inserted into an image in a manner whereby each bit is represented by a PN sequence and these n sequences are added or subtracted depending on whether the value of the corresponding bit is zero or one (See United States Patent No. 5,636,292 to Rhoads). Many other methods known in the art are also possible. These different methods have different characteristics with regard to robustness, fidelity, resistance to tampering, such as counterfeiting and collusion attacks, which are described

in more detail subsequently, and requirements at the detector, e.g., secret keys and restricted access to the watermark.

It is becoming apparent that users may wish to insert several types of information, e.g., owner identification, buyer identification and copy control information. And different types of information may have different requirements regarding the compromises to be made between characteristics such as robustness, fidelity, and resistance to tampering. However, in the prior art, all the information encoded by a watermark has been treated equally.

There are three significant classes of watermark signal, namely watermark signals that are immune from counterfeiting, watermarks that are resistant to collusion attacks and public watermarks for which no secret information is needed at the detector. These three classes of watermark signal can possess very different characteristics. For example, a watermark signal that is immune to counterfeiting cannot also be a public watermark.

S. Craver et al., *Resolving rightful ownerships with Invisible Watermarking Techniques: Limitations, Attacks and Implications*, IEEE J. Selected Areas of Communications, 16, 4, 573-586, (1998) (hereinafter "Craver") describes a situation in which rightful ownership cannot be resolved by a straightforward application of watermarking. In particular, a situation is identified in which anyone could claim ownership of a watermarked image through a process whereby a counterfeit watermark is inserted. Craver's solution to this problem is to use a method called "non-invertible" watermarking. The basic idea behind this method is to construct a watermark based on a non-invertible function of the

original image. An example of a non-invertible function is a one-way hash function commonly used in cryptography. Such a function takes a string of bits as input and outputs a finite output, for example, a 1000-bit output. Given the 1000-bit output, it is computationally infeasible to determine the corresponding input. Such a watermark can only be read by the content owner or someone in possession of the original image or its hashed key. Thus, a public watermark, i.e., a watermark that can be read by anyone, cannot be non-invertible or, at least the benefits of non-invertibility are lost since all readers must have knowledge of the hashed value.

Another issue to do with tampering with watermarks is discussed in Cox et al., *Secure Spread Spectrum Watermarking for Multimedia*, IEEE Transactions on Image Processing, Vol.6, No.12, pp.1673-1687, 1997. This problem occurs when there are many copies of the same original image, each copy having a different watermark. Then, owners of these copies can collude together in an attempt to remove the watermark. For example, a simple collusion scheme would be to average together all of the available copies. Other more sophisticated methods also exist. United States Patent No. 5,664,018 to Leighton (hereinafter "Leighton") shows that in such a situation, the most robust form of watermark is drawn from a Normal Guassian distribution rather than a binary distribution. Such an attack would be as effective on either invertible or non-invertible watermarks. Unfortunately, Leighton's proposal only maximizes the number of copies of an original that are needed before the watermarks are removed. It does not prevent a collusion attack but simply makes it somewhat more difficult. However, in practice, the number of copies needed is still relatively small.

The present invention is concerned with the broad problem of inserting both owner and buyer identification information into content in as secure a way as possible. What is needed is a robust watermarking system in which some portion of the watermark remains fixed in all watermarked copies of an original and the remaining portion may vary with each copy.

Further, the fixed watermark is constructed from a non-invertible function of the image so that a counterfeiting attack is not possible. The copy-specific portion of the watermark can also be constructed to be non-invertible although some fraction of this might also be invertible to allow anyone to read them.

The present invention provides a watermark signal which can be constructed such that a portion of the data encoded in the watermark signal possesses one set of characteristics while other portions of the data are encoded so as to possess different characteristics.

Accordingly, a method for inserting at least two messages into digital data to be watermarked is provided. The method comprises the steps of: representing each of the messages with an individual signal such that all of the individual signals, when combined, do not interfere with one another and each signal has its own robustness characteristics; combining the individual signals to create a watermark signal; and inserting the watermark signal into the digital data to be watermarked.

Also provided is a method for detecting a target message from digital data containing at least two watermark messages. The method comprises the steps of: extracting a watermark signal from the data, the watermark signal containing an individual signal corresponding to each of the at least two watermark messages; removing all but one

of the individual signals from the watermark signal; and decoding the remaining individual signal to obtain the target message.

These and other features, aspects, and advantages of the methods of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawing where:

FIG. 1 illustrates a schematic of the insertion method of the present invention.

Although this invention is applicable to numerous and various types of digitized data, it has been found particularly useful in the environment of digital video data. Therefore, without limiting the applicability of the invention to digital video data, the invention will be described in such environment.

The final watermark that is inserted in a image can be considered to consist of a string of symbols, where each symbol is represented by a pattern and the watermark is constructed by the addition or subtraction of this pattern. For a binary watermark consisting of N-bits, each bit would be represented by a unique pattern and each pattern would be added or subtracted depending on whether the corresponding bit was zero or one. A watermark does not have to contain only binary bits. For example, the non-varying data to be inserted in each copy of an image can be represented by a single pattern. When this pattern is detected, the information associated with the pattern can be determined through a database, which is indexed by patterns.

Thus, the general problem is to (i) securely insert R patterns into an image, where $I \geq 1$ patterns represent copy independent information and R-I patterns may vary with

each copy and (ii) detect these patterns when only a subset may be present in the degraded image.

Figure 1 illustrates the basic ideas behind insertion. The original image 100 is passed through a one-way hash function 102, such as the NST SHA-1 function, to produce a k-bit key that is image dependent. This key is then used as the seed to a pseudo-random number generator 104. The generator may be binary or continuous and might provide one of many distributions including uniform and Normal.

K-values from the PN generator are used to form the pattern associated with the copy-independent data. We assume that the copy-dependent data consists of Q binary bits, though this is not necessary. Each of the Q-bits is represented by an L-dimensional sequence of values from the PN generator. Finally, we assume R additional bits of information, which are represented by a set of M-dimensional values that are not content dependent.

The dimensions of each set of patterns may be equal, i.e., K=L=M, and may equal the dimensions of the image. However, in general they need not be equal and may be considerably less than the dimension of the image, depending on the type of embedding method that is used. For simplicity, we will assume that the Q-bits and R-bits have identical dimension to that of the copy-independent data.

Mathematically, we have S=P+Q+R patterns that must be embedded in the content. Without loss of generally, we can assume that P=1, and let A denote the copy-independent pattern. The remaining Q+R patterns are either added or subtracted, depending on whether their corresponding bit is zero or one. For mathematical convenience, we assume a bipolar bit pattern, i.e.,

values of ±1. Let B denote the bit pattern to be embedded. Note that B may also include error correction code bit as well as data bits.

M-bit data is coded by error-correction coding to enhance robustness. Two types of linear block codes, namely the Hamming code and Binary BCH code, have been studied [See R.E. Blahut: *Theory and Practice of Data Transmission codes*, 2nd edition (draft), 1977; J.G. Proakis: *Digital Communications*, 3rd edition, McGraw Hill, 1995; and C.B. Rorabaugh: *Error coding cookbook*, McGraw Hill, 1995]. IN the preferred implementation of the present invention, the following notation of coding is followed:

[n,m,d,t]		Linear block codes
n	-	codeword length in bits,
m	-	number of data bits,
d	-	minimal Hamming distance between codewords, that is, the minimum number of different bits between codewords,
t	-	maximum number of bit errors within every n-bit codeword that can be corrected, with d = 2t + 1.

The Hamming code is one of the simplest error correction codes. It is a linear black code with specification of $[2^k - 1, 2^k - k - 1, d = 3, t = 1]$, where k is a positive integer. There are several common settings of k, among which [See e.g., ELE539 *Theory and Practice of Channel Coding*, Class Notes, Princeton University, Spring, 1998; R.E. Blahut: *Theory and Practice of Data Transmission Codes*, 2nd edition (draft), 1997; and I.J. Cox, et al.: *Secure Spread Spectrum Watermarking for Multimedia*, IEEE Trans. on Image Processing, Dec.m 1997]. However, the minimal distance of different k is always three, hence it can always correct one and only one bit error for every n bits. Meanwhile, the Hamming code has the following

property that is called n perfect code [See R.E. Blahut: *Theory and Practice of Data Transmission Codes*, 2nd edition (draft), 1997; and ELE539 *Theory and Practice of Channel Coding*, Class Notes, Princeton University, Spring, Fig. 3, 1998] in an n-dim binary space each vector is denoted as a point. If a ball is drawn with a valid codeword as its center and t as the radius, such a ball will enclose all vectors that can be corrected as the center codeword vector. The union of all balls of hammering code will occupy the whole space without leaving any dot outside it. In other words, any vector in this space will be associated with one ball and corrected to a valid codeword, even though that vector may be a noisy version of a codeword in another ball. Such perfectness is not desirable in multiple-bit watermark application since we risk getting bit errors after decoding when the watermarked image experiences heavy distortions.

Binary BCH coding is more complicated, but a more powerful error correction method than the Hamming code. This code is used in a variety of practical applications due to the existence of computationally efficient and easily implemented decoding procedures. The error correction ability can be chosen from a number of settings. Unlike the Hamming code, BCH code has very low density for certain specifications. For example, in BCH [511,76,t=85] code, the balls described above only enclose 10^{-31}% of points. The points outside will be detected as invalid codeword but will not be correctable. In other words, if the test code vector is very noisy, the probability that the detector fails to determine this and output an incorrect m-bit vector is 10^{-33}. This is desirable for multiple-bit watermarking because we want to determine how noisy the received code vector is and to avoid correcting a noisy one to a wrong one.

Other powerful error corrections codes are also possible, such as convolutional code and Turbo code [See R.E. Blahut: *Theory and Practice of Data Transmission Codes*, 2nd edition (draft), 1997; J.G. Proakis: *Digital Communications*, 3rd edition, McGraw Hill, 1995; C.B. Rorabaugh; *Error coding cookbook*, McGraw Hill, 1995; and ELE539 *Theory and Practice of Channel Coding*, Class Notes, Princeton University, Spring, 1998].

Returning now to the patterns, let C denote the (Q+R) patterns, i.e., C is a L x (Q+R) matrix. The matrix C can be thought of as a modulation matrix, each column of which represents the chip sequence (to use terminology from spread spectrum communications) for that particular bit. The columns of C should be orthogonal. This property can be constructed in a variety of ways including Gramm-Schmidt matrix orthogonalization or, for example, by constructing a matrix in which there is only a single non-zero entry in each row. For images and video, this latter case corresponds to the situation in which each bit is encoded in a spatially disjoint region of the image. Another alternative is to generate n L-dimension orthogonal vectors by randomizing a set of known orthogonal basis obtained in advance. A Hadarmard matrix is an example. It is composed of only +1 and -1 elements and is known to be orthogonal and symmetric. The process is summarized as follows:

1) Obtain L x L Hadarmard Matrix and randomly select n column vectors to form an L x n matrix.

2) Each row of the L x n matrix is multiplied by a random binary number (+1 or -1) generated by seeds which can be a function of the original image, hence the set of L-dimension orthogonal image and the orthogonality is maintained.

3) Columns of the randomized L x n matrix are normalized such that the resulted matrix M satisfies M'M =I (identify matrix).

The L x n matrix in the first step can be stored beforehand and used for watermarking many images.

Thus, the final signal to be inserted, D is

$$D = A + C.B$$

The signal D may be inserted into the image in a variety of well-known ways.

To detect this data, it is important to realize that the image containing the watermark may have undergone significant degradations due to normal use and intentional attacks aimed at removing the watermark. Consequently, all the patterns that were inserted may not be present at the time of detection. Thus, we wish to detect each group of patterns independently.

In the case where the image noise is not dominant, the primary noise source can be the presence of the other patterns. This situation is common when the original unwatermarked image is used as part of the detection process and can occur in more advanced watermark embedding systems. In particular, we have described three message classes; copy independent/image specific, copy dependent/image specific and copy dependent/image independent. Each message class has different robustness properties and may or may not be present in the received image. Thus, we need to detect each class independently. However, in the case where the other message groups are present, these signals appear as noise and, as mentioned earlier, may be the dominant noise source. As such, we would like to minimize their effect on the detection

process.

If D' denotes the detected signal, then

$$D' = A + C.B + \text{noise}$$

Ignoring the noise term, we can optimally detect for A by applying Gramm-Schmidt orthogonalization such that

$$E = D' - C.(D.C^T)$$

and then applying a statistical test between the known vector A and the estimated vector, E, such as the well known correlation coefficient

$$\text{corr} = \frac{E.A}{\sqrt{(A.A)(E.E)}}$$

Similarly, to detect the data bits, we first remove any contribution that may be present from A, i.e.,

$$F = D' A(D.A^T)$$

And again perform a statistical test between F and our best estimate of the pattern of bits present, B'. Our best estimate of the B bits is given by

$$B' = (D'.C^T>0)?1:-1$$

i.e. we correlate the received signal with the Q+R patterns. If the correlation value is greater than zero then the corresponding bit is assumed to be 1, otherwise it is -1. Of course, even when no bits are present, we will derive a vector B' and this is why it is necessary to subsequently test the statistical significance of the estimate. Again, a variety of tests may be applied,

including the correlation coefficient

$$corr = \frac{F.G_T}{\sqrt{F.FG_T.G_T}}$$

where G = C.B' is the encoded signal for B'.

It should be noted that the above discussion has considered the two copy dependent message groups as one, but it is straightforward to treat these two groups separately.

While there has been shown and described what is considered to be preferred embodiments of the invention, it will, of course, be understood that various modifications and changes in form or detail could readily be made without departing from the spirit of the invention. It is therefore intended that the invention be not limited to the exact forms described and illustrated, but should be constructed to cover all modifications that may fall within the scope of the appended claims.

WHAT IS CLAIMED IS:

1. A method for inserting at least two messages into digital data to be watermarked, the method comprising the steps of:

representing each of the messages with an individual signal such that all of the individual signals, when combined, do not interfere with one another and each individual signal has its own robustness characteristics;

combining the individual signals to create a watermark signal; and

inserting the watermark signal into the digital data to be watermarked.

2. The method of claim 1, wherein at least one of the individual signals is based on a non-invertible function of the digital data.

3. The method of claim 1, wherein at least one of the individual signals is based on an invertible function of the digital data.

4. The method of claim 1, wherein at least one of the individual signals is based on an invertible function of the digital data and at least one other of the individual signals is based on a non-invertible function of the digital data.

5. The method of claim 1, wherein at least one of the individual signals is copy independent.

6. The method of claim 1, wherein at least one of the individual signals is copy dependent.

7. The method of claim 1, wherein at least one of the individual signals is copy independent and at least one other of the individual signals is copy dependent.

8. The method of claim 1, wherein the individual signals are orthogonal vectors.

9. The method of claim 8, wherein the orthogonal vectors are generated by Gramm-Schmidt orthogonalization.

10. The method of Claim 1, further comprising the step of encoding each message using an error correction code prior to representing it as a corresponding individual signal.

11. The method of claim 10, wherein the error correction code is a BCH code.

12. A method for detecting a target message from digital data containing at least two watermark messages, the method comprises the steps of:

extracting a watermark signal from the data, the watermark signal containing an individual signal corresponding to each of the at least two watermark messages;

removing all but one of the individual signals from the watermark signal; and

decoding the remaining individual signal to obtain the target message.

13. The method of claim 12, wherein the removing step is carried out be Gramm-Schmidt orthogonalization.

14. The method of claim 12, wherein the decoding step is

carried out by:

comparing the remaining individual signal against a known individual signal corresponding to a possible content of the target message thereby obtaining a statistical detection measure; and

comparing the statistical detection measure against a threshold to determine whether the remaining individual signal decodes into the target message content represented by the known individual signal.

15. The method of claim 14, wherein the known individual signal is obtained by applying a non-invertible function to the digital data.

16. The method of claim 12, wherein the decoding step comprises the sub-steps of:

multiplying the remaining vector by a demodulation matrix to obtain a demodulated signal;

thresholding elements of the demodulated signal to obtain a bit pattern; and

decoding the bit pattern to obtain the contents of the target message.

17. The method of claim 16, wherein the decoding of the bit pattern is carried out by error correction code.

18. The method of claim 17, wherein the error correction code is a BCH code.

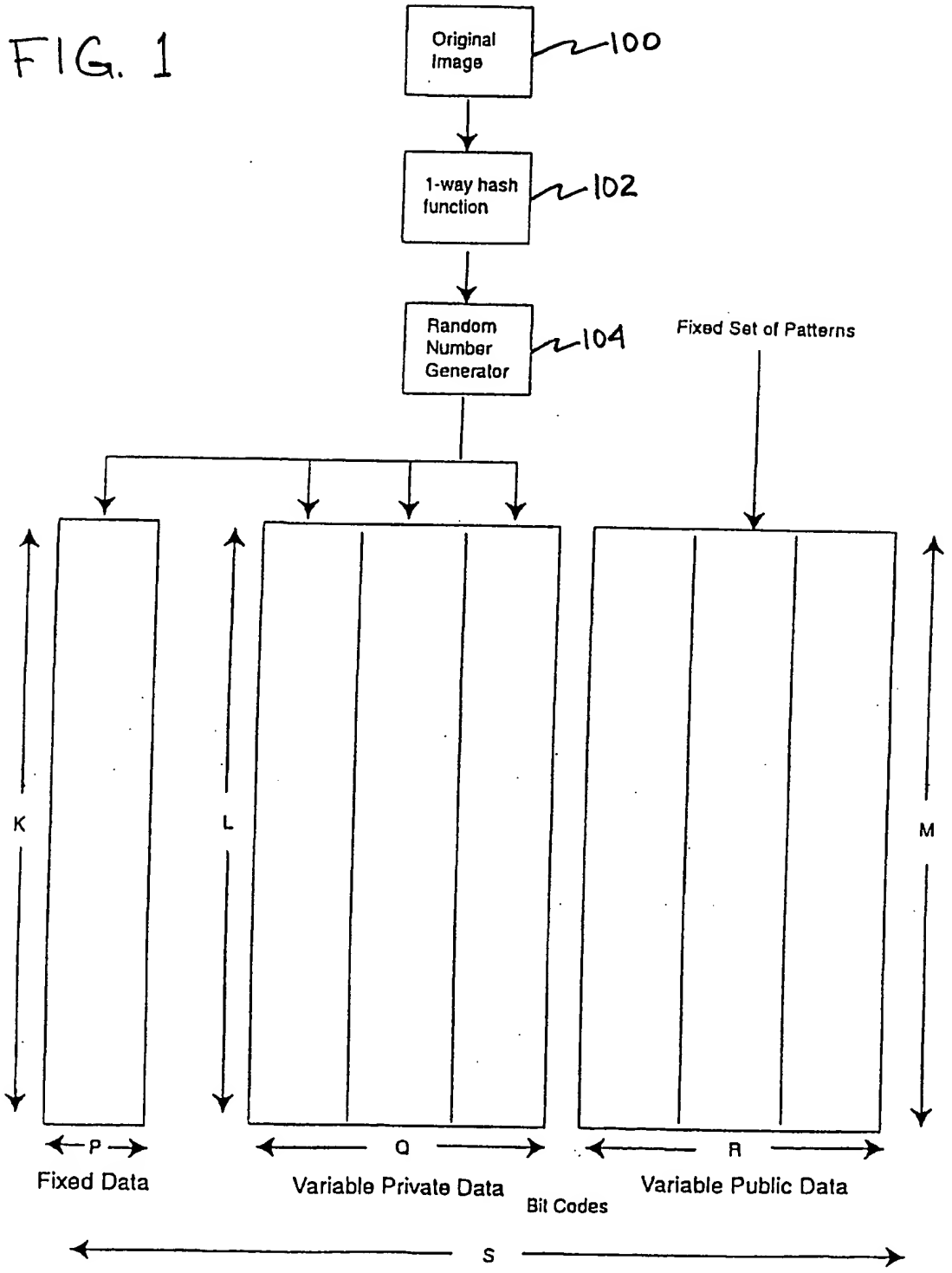
19. The method of claim 12, further comprising the sub-steps of:

re-encoding the target message as an individual signal;

comparing the re-encoded individual signal against the remaining individual signal thereby obtaining a statistical detection measure; and

comparing the statistical detection measure against a threshold to determine whether the remaining message is valid.

FIG. 1


Original Image
100
1-way hash function
102
Random Number Generator
104
Fixed Set of Patterns
K
L
M
P
Q
R
Fixed Data
Variable Private Data
Variable Public Data
Bit Codes
S

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/11264

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : G09C 5/00, 1/00

US CL : 380/54, 4, 25

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 380/54, 4, 25

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Internet - http://www-nt.e-technik.uni-erlangen.de/~hartung/watermarkinglinks.html

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS "watermark"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,809,139 A (GIROD et al) 15 September 1998, col. 9, lines 19-23	1, 8, 10-13, 16-18
----- Y		----- 2-7, 9, 14, 15, 19
Y	US 5,613,004 A (COOPERMAN et al) 18 March 1997, col. 16	2-4, 15
Y, P	US 5,905,800 A (MOSKOWITZ et al) 18 May 1999, col. 1, lines 1-36	5-7
A, P	US 5,848,155 A (COX) 08 December 1998, col. 6, lines 1-9	14, 19

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Date of the actual completion of the international search 13 AUGUST 1999	Date of mailing of the international search report 30 SEP 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-0040	Authorized officer STEVE KABAKOFF James R. Matthews Telephone No. (703) 306-4153

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/11264

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	COX et al, Secure Spread Spectrum Watermarking for Multimedia, IEEE Trans. Image Processing, December 1997, Vol. 6, No. 12, Fig. 3 and Eq. 4	14, 19
Y	US 5,319,586 A (GUPTA et al), 07 June 1994, col. 5	9
A	CRAVER et al, Can Invisible Watermarks Resolve Rightful Ownerships?, IBM Research Report, July 1996, RC 20509, Section 5	2-4, 15